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Climate policies: a burden, or a gain?

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Abstract: That climate policies are costly is evident and therefore often create major fears. But the alternative (no action) also has a cost. Therefore, mitigation costs netted of the damage costs avoided are the only figure that can seriously be considered as the "genuine cost" of a policy. We elaborate on this view of a policy's cost by distinguishing between its "direct" cost component and its avoided damage cost component; we then confront the two so as to evaluate its genuine cost. As damages avoided are equivalent to the benefits generated, this brings climate policies naturally in the realm of benefit-cost analysis. However, the sheer benefit-cost criterion may not be a sufficient incentive for a country to be induced to cooperate internationally, a necessary condition for an effective global climate policy. We therefore also explore how to make use of this criterion in the context of international climate cooperation.

Keywords: climate policy, integrated assessment models, benefit-cost analysis, international cooperation

JEL codes: Q2; D9

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1. Introduction

That climate policies are costly is evident and therefore often creates major fears in industry. Understandably so: actions of mitigation of GHG emissions require considerable resources hence entail high costs. Actors of industrial life consider this as a burden for our economies. Is it a bearable one?

To appreciate that, consider the alternative, i.e. no action, and *its* cost: no action means our economies incurring damages, possibly considerable (see IPCC (2007), which will also be a burden. There are two categories of costs, one caused by climate change (damages incurred), the other caused by climate policy (mitigation costs) which in any sensible cost-benefit analysis of abatement policies have to be considered jointly. However, the amounts of each of the two terms in the sum vary depending upon what the policies are. In fact, they are substitutes: indeed, the more mitigation and adaptation actions, the less damages will be incurred, and the less of the former, the more of the latter. The reverse also holds: severe adverse climate impacts provide strong incentives for emission abatement. This naturally follows from realizing that policies aim at *avoiding damages*. In that perspective, avoiding damages appears to be the *benefit* that accompanies climate policies. And if that benefit appears to be larger than the mitigation and adaptation cost (the "direct" cost, for short), such policies can be deemed economically sound. Actually, costs and benefits are the two sides of a same coin.

This reasoning brings climate policies naturally in the realm of benefit-cost analysis, a well-established instrument of decision-making in the public sector. In this paper, we wish first to simply illustrate the "direct" cost component of various policies (Section 2), then to confront them with the benefits generated, that is, the damage cost avoided (Section 3) and draw (in Section 4) preliminary conclusions on the policies' respective justification. The purpose here is mostly to offer the reader information on the orders of magnitude as provided by published advanced models, thereby avoiding to enter into the details of these.

In climate affairs, there is however an additional dimension to the benefit side just identified. In the way it is invoked above, the benefit-cost criterion makes no reference to the multi-national component of the issue. When the problem that requires action is of exclusively national nature, benefits as well as costs are those that accrue to the country and these only determine the decision. Transposing benefit-cost analysis to enlighten decision-making on issues with international impacts cannot simply consist in an addition of national benefits and costs of domestically chosen strategies. In a multi-national context, there is often – and certainly in the climate change case – a *superadditive* aspect to the possible joint actions by the countries, in the sense that together they can *(i)* do more that the sum of their alternative individualistic policies, and (*ii*) generate a larger joint benefit than the sum of their benefits when acting individualistically.

Therefore, the sheer domestic benefit-cost criterion is not a sufficient incentive to induce the synergies needed to achieve efficiency at the world level. Additional and specific motivations of some sort for adopting non-individualistic policies are called for. What can they consist of? In Section 5 we advocate for and illustrate the role of inter-country transfers to go beyond the standard framework of selfish national benefit-cost analysis to implement an efficient international climate agreement.

2. What is the cost of a climate policy?

2.1 The policy's direct cost as a burden for the economy

A comprehensive and interesting synthesis of the direct cost approach is provided in the survey by Edenhofer *et. al*. (2010). This survey covers four major numerical simulation models that are widely used in policy discussions, namely: MERGE (Kypreos and Bahn, 2003), REMIND-R (Leimbach *et al.*, 2010), POLES-ETSAP (European Commission, 1996) and TIMER (Bouwman *et al.* 2006). All models project how the economy may evolve spontaneously in the future (about a century), and then examine how a couple of discretionary climate policies affect the estimated evolution of the GDPs, both national and at the world level. The policies considered are expressed in terms of *global caps* either on emission levels, or on carbon concentration in the atmosphere, or still on average temperature increase. These caps are introduced as exogenous constraints in the models, which for the rest are optimal growth models.

As to how the burden is measured, in the MERGE and REMIND models the cost is measured as discounted cumulative GDP losses up to 2100 relative to some baseline, and it is expressed in percent of the baseline GDP over the same period. The POLES and TIMER models report instead the increase in abatement costs relative to the baseline, also expressed in percent of GDP. For all models the discount rate is 3 percent a year and net present values are calculated with 2000 as the base year. The results are reported in figure 7 in Edenhofer *et. al*. (2010, page 31).

Edenhofer *et al*. (2010) focus on three policies. All of them are expressed in terms of alternative caps on global GHG concentration in 2100, respectively of 400, 450 and 550 ppm CO_2-eq. Two key conclusions emerge from this model comparison. First, the direct costs of the policies considered are small: the 550 ppm cap entails a 0.8% cumulated loss of world GDP in 2100, the 400 ppm cap a 2.5% loss. Second, despite differences in the orders of magnitude, all models agree on the qualitative message that policy costs are limited.[3]

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[3] It can be noticed that, in this model comparison, the choice of the policy instruments that would be able to implement the policy within and among the countries is not discussed. This boils down to assume that these instruments are cost-effective, like a global carbon tax. In other words, the global effectiveness of the scenarios is analyzed disregarding the issue of their national implementation. See Bosetti and Victor (2011) for a discussion on that point.

2.2 The policy's genuine cost

In case of "no policy", what is the burden? Is there at all a cost for the economy? What we have described above as "direct" costs are absent, since no action entailing them – mitigation or adaptation – is taken in that case. Unfortunately, this is only one side of the coin, as other costs are involved. Indeed, global warming has powerful physical impacts on earth such as storms, coastal erosion, sea level rise and droughts. These in turn entail *damages* that are materialized in losses of economic goods, properties and assets, let alone human lives. These damages are sheer destructions of parts of the economy, and they are maximal in case of no action. Clearly there is a cost of doing nothing.

But policies, if rational, aim at reducing damages. Therefore, the genuine cost to society of any climate policy is to be thought of as a number which is net of the damage costs the policy allows one to avoid — in other words, it is the number obtained by subtracting the value of the avoided damages from the burden of the direct cost described above. If negative, this genuine cost is obviously a net benefit, implying that the policy is justified according to the standards of benefit-cost analysis.

It is important to note at this point that for any country the benefits as well as the costs are not to be considered in isolation: their magnitude also depends on the policies implemented abroad, be they the result of international agreements or not. This extension of the reasoning will be the topic of Section 5.

3. Evaluating two policies in terms of their genuine cost

The most striking example of a statement on climate change made recently in the spirit of benefit-cost analysis is the Stern Review (Stern, 2007). Using an integrated assessment model (henceforth IAM) of the world economy, namely the PAGE model, the Review estimates that, *for the policies it defines*, benefits in terms of value of damages avoided would range between 5 and 20 percent of world GDP every year and for ever, whereas mitigation costs to achieve this damage avoidance would amount to about 1 to 2 % of world GDP, every year and for ever. We propose to apply the same reasoning to two among the policy choices studied in Edenhofer *et al*. (2010), namely the 650 and 550 ppm caps, and check whether or not they pass the benefit-cost criterion. We do this by using our own IAM, namely CWS (for CLIMNEG World Simulation)[4], so as to see whether a result such as Stern's can be obtained by means of this alternative measurement tool.[5]

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[4] A full description of the CWS model (including parameter values) can be found in Bréchet et al. (2011) for the 6-region version, and in Bréchet et al. (2012) for the 18-region version (which is, by the way, also stochastic).

[5] See Kolstad and Toman (2005) for an introduction and overview of integrated assessment climate-economy models, Bréchet and Luterbacher (2014) for a discussion on their usefulness for policy support and Bréchet and Eyckmans (2012) on how they support some political economy concepts to manage the global commons.

The CWS model is to close the original RICE model by Nordhaus and Yang (1996) or its variations as in Eyckmans and Tulkens (2003), Yang (2008) and Bréchet *et al*. (2012). In the model, the world is split into 18 regions or countries. An essential characteristic of an IAM is the endogenous feedback between the economy and the climate. Decision variables are capital accumulation (to sustain economic growth) and GHGs emission abatement (to control climate change). CWS can also be seen as a general equilibrium model in the sense that all the dimensions of the economy are endogenous, in particular capital accumulation. The model consists of an optimal control problem in which investment in physical capital and abatement efforts are the control variables and temperature change is the state variable. The objective function to be maximized is the intertemporal welfare expressed as the discounted green consumption (Z), i.e. gross output (Y, driven by capital accumulation and population growth) net of investment in capital (I), emission abatement costs (C) and climate damages (D, driven by GHGs concentration and temperature change), so that we have $Z = Y - I - C - D$ for all countries and at all time periods. The alternative policies to be examined below are introduced, as mentioned above, as alternative constraints on the GHG concentration that results from the emissions generated by the gross output.

From the model's solution we compute as follows, in terms of the distinction made in Section 2, the aggregate cost of any policy, say "policy P". The direct cost is denoted C_P ; the damage cost it allows to avoid is $(D_{BAU} - D_P)$, where D_{BAU} is the damage cost that would occur under the "business as usual" (i.e. no policy) benchmark scenario (to be defined shortly), and D_P is the damage cost that remains incurred under the policy P. This yields the genuine cost of policy P (GC_P) as

$$GC_P = C_P - (D_{BAU} - D_P). \tag{1}$$

3.1 The genuine cost of the cap-650 ppm and cap-550 ppm policies

Let us consider the following two global *policies*:

- "cap-650 ppm": a policy of global emissions abatement which ensures optimal growth of the economy by (i) maximizing present and future green consumption, that is, net of both the abatement and damage costs entailed by the policy, and (ii) constraining abatements to the condition that the concentrations they entail in the atmosphere never exceed 650 ppm CO_2-eq over the period 2000-2100.
- "cap-550 ppm": a similar policy with the only difference that the global concentration is constrained never to exceed the tighter bound of 550 ppm CO_2-eq.[6]

[6] With the 400 ppm cap constraint, the CWS model has no feasible solution, as it is the case with many other models mentioned in Edenhofer et al. 2010. Thus, for most climate-economy models reviewed here, this cap cannot be reached. A view shared by many climatologists, actually. This is the reason why we consider only 550 and 650 ppm caps in this paper.

We wish to compare these two policies with two benchmark *scenarios* that are common in the literature:

- "BAU": Business as usual, which means no discretionary abatement policy and thus no abatement costs; damage costs are as they result from the *laissez faire* emissions that accompany the natural growth of the economy and no constraint applies to CO_2 concentration.
- "COOP": Optimal abatement policy at the world level, i.e. the one that maximizes present and future green consumption without binding constraint on CO_2 concentration.

In other words, the "BAU" scenario is the pure case of "no action" in the framework of a world market economy, whereas "COOP" describes the best global outcome that can be achieved, according to the CWS model, in combining economic growth and environmental protection, with no institutional framework being specified for its achievement and no redistributive effects among countries being taken into account either.

To sum up, we thus consider two *policies* and two *scenarios* in this section. The first two (henceforth "cap-650" and "cap-550") are well-defined programs of global action (i.e. action at the world level), whereas the other two ("BAU" and "COOP") are only benchmarks provided for the sake of comparison. The former describes an environmentally "worst" case in a growth context, and the latter an environmentally "best" case compatible with growth.

Figure 1 displays the time profiles of GHGs emissions implied by these two policies and the two benchmark-scenarios. Thus for example, optimal economic growth under the "cap-550" policy implies to let global emissions increase up to 9.7 GtC per year in 2060 and then to let them decrease down to 5.0 GtC per year in 2100. As for the "cap-650" policy, the maximum yearly emissions are higher (14.1 GtC) and are reached only later, in 2080.

It is interesting to see that these two policies generate emission levels far below those of the worst case: thus, the cap-550 policy requires in 2100 global emissions to be reduced by 76 percent with respect to those of the "BAU" scenario. This policy also succeeds in bringing emissions back to their level of the year 2000. It is also interesting to notice that in both policies emissions are below those of the "best" scenario, as calculated by the CWS model. Note in particular that emissions under the cap-650 policy are close to those of the COOP scenario for a major part of the time period covered.

< Please insert Fig. 1 around here >

Let us now consider the respective genuine costs of these policies and scenarios, as described by Equation (1).

As far as the direct costs C_P components are concerned, we do the analysis with the same kind of calculations and graphs as used by Edenhofer *et al*. (2010). Thus, we calculate C_P as the cumulated yearly losses in world GDP up to 2100, discounted at a 2-percent yearly discount rate. These costs appear on Figure 2 where one can see that for the two policies the direct costs are, respectively, a 1.1 percent loss in cumulated GDP for the "cap-550" policy, and a 0.4 percent loss for the "cap-650" policy. These cost numbers are of an order of magnitude similar to those provided by Edenhofer *et al.* (2010) and reported above. Climate damage costs avoided with respect to the BAU scenario ($D_{BAU} - D_P$) in either policy are presented in the same way on Figure 2. The cumulated such avoided costs are respectively of 0.4 percent of world GDP for the 550 ppm policy and 0.3 percent for the 650 ppm policy.

Finally, the genuine costs of the two policies appear as the right bars of Figure 2. Being positive, these bars reveal that the cumulated damage costs avoided by these policies do not outweigh the cumulated direct costs. But when these are netted out of the damage costs avoided, their genuine costs become respectively only 0.6 percent and even 0.1 percent of world GDP. Obviously, when the presentation of the policies' cost is restricted to the direct costs only (1.1% and 0.4% of GDP respectively as just mentioned), the picture is overestimated. And the overestimation is of 67% for cap-550 and 258% for cap-650 when the comparison is made with the genuine cost. We feel that this overestimation is so large that it cannot be ignored in the political debate.

< Please insert Fig. 2 around here >

To further evaluate these policies, we now turn to the other benchmark, namely the "COOP" scenario, as computed with the CWS model. By definition this scenario is optimal, i.e. it maximizes world welfare, measured by the green GDP denoted above as Z and it specifies no cap *a priori*: the optimal path of CO_2 concentration in this scenario is simply the one determined by the emissions labeled COOP on the Figure 1. Here we obtain that the damage costs avoided outweigh the direct costs as shown by the three bars in the right part of Figure 2. The genuine cost of this optimal scenario is thus negative which implies that a policy that would implement this scenario is profitable at the world level.

Compared with COOP, the fact that the two policies with the constraints of 550 ppm and 650 ppm, respectively, have a higher genuine cost shows that these constraints are too stringent: these policies overshoot. Because of their excessive stringency, both policies are even worse than the business-as-usual scenario. Of course, this holds given the considered numerical parameters in our model. The bars in the left and middle parts of the Figure further suggest that this overshooting is entirely due to the higher abatement cost, since under either one of them, the sum total of the damages avoided is higher that in the COOP scenario.

It must be emphasized that very large uncertainties prevail in the economic evaluation of climate damages, on the choice of the functional form of the damage functions used in integrated assessment models (such as CWS), and on the calibration of these functions. Even if uncertainties affect all aspects of the costs entailed by climate change, criticisms often concentrate on the fact that damage costs are very crudely estimated, which we acknowledge. This field does require continuing research efforts. Proposing an alternative calibration for the damage functions to make these estimates more reliable in IAMs is not within the scope of this paper.[7] But checking the robustness of our results against such uncertainties surely deserves attention. It can be done by carrying out a sensitivity analysis on the parameters of these functions so as to have an idea of how they impact the results.

3.2 A sensitivity analysis

Given our concern with the avoided damage costs we provide here a sensitivity analysis bearing on the damage cost function used in the CWS model. This increasing function is of the exponential form, with the exponent assumed to be 2.0 in all countries in the previous calculations. In this section we change this parameter to 2.7, making the common damage function much steeper.

The computational results are first displayed in Figure 3 for world GHG emissions. By definition, the emission profile is strictly the same for the "BAU" scenario. But two very interesting and innovative results come out from this figure.

The first one is about the time profile of GHG emissions in the cap-550 and cap-650 scenarios, which differ from Fig. 1. Remember that the constraints are to not outreach the stated cap on GHG concentration. The model thus determines the optimal growth i.e. the one that maximizes intertemporal green consumption if the economy operates under these constraints. Because climate damages are now evaluated to be heavier, their impact on welfare is also stronger, which pushes the countries to devote more resources to abatement of emissions. This is illustrated in Fig. 3 for the cap-550 policy case: the maximum emission level is now 9.0 GtC, while it was 10.0 GtC previously (both reached in 2070). Eventually this increase in abatement translates into a smaller green consumption level (not shown on the Figure).

The second appealing result is that the "cap-650" policy now coincides with the "COOP" scenario over the whole simulation period. Thus, this policy brings the world on a green consumption path virtually identical to the one that maximizes world welfare (under our parameter values). This reveals that the world optimal solution ("COOP") is far from being completely unrealistic from a

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[7] Climate sensitivity is also one of the key uncertainties. In a stochastic version of the CWS model with risk aversion, by taking this uncertainty into account we show that cooperation among countries actually brings a double benefit : it increases global welfare, and also sharply reduces the risk of high climate damages. See Bréchet et al. (2012).

policy standpoint and should not be considered as purely theoretical. Sometimes the best can be achieved. In other words, and in the reverse perspective, prescriptive policies discussed today in the political area (here, “cap-650”) may meet the normative analysis (here, “COOP”). Although environmentally more stringent, and therefore perhaps politically more attractive to some, the “cap-550” policy is not better welfarewise because it restricts green consumption too much: it is actually too stringent.

Let us now turn back to the genuine costs and their components by using the same presentation as in Section 3.1. The fact that the countries are more sensitive to temperature increases translates into our two given policies entailing larger abatement efforts than before (for the “cap-550”policy: 1.2% against 1.1% previously; for “cap-650”: 0.9% against 0.4% previously) as well as larger damage costs avoided. This appears from comparing Fig. 4 with Fig. 2.

What is the new balance between direct costs and damage costs avoided? Fig. 4 shows that the “cap-550” policy entails higher direct costs than damage costs avoided, this resulting for the genuine cost in a 0.05% net GDP cumulated loss over the century. The policy is thus not socially profitable. By contrast, the balance is positive for the “cap-650” policy (expressed by a negative genuine cost of 0.17%). The “cap-650” policy thus passes the benefit-cost criterion, just like the scenario it is identical to.

< Please insert Fig. 3 and Fig. 4 around here >

The question of whether our results are sensitive to the choice of the discount rate cannot be avoided. In the paper we consider a low discount rate (2 percent per year). Choosing a higher discount rate would unambiguously yield the following outcome: (*i*) both cumulated discounted direct costs and damage costs avoided would be lower; (*ii*) however, the balance between the two categories would move in favour of the direct costs, because these costs are borne in the short term while avoided damage costs only occurs in the long run; (*iii*) as a result, the genuine costs of the two policies (550 and 650 ppm) would increase, this corresponding to a lowering of the benefit/cost ratio.

4. Regional acceptability: a necessary condition for reaching an international agreement

Regional/national acceptability relies on a regional/national cost benefit analysis. Even though climate change is a global public bad, costs and benefits are local because both are experienced at the regional/national scale. Highlighting regional costs and benefits for a given policy is thus key to understand national political standpoints in the international negotiations process. Even though many papers in the literature pay attention to the spatial differentiation of costs and benefits of climate policies (see, e.g. Bosetti et al. (2013), Cantore (2011), Kemfert (2004), Lessman and Edenhofer (2011) or Nagashima *et al*. (2009)), none of them explicitly use our genuine cost concept to characterize countries' negotiation position.

The previous analysis confirms that the genuine costs of the two policies discussed are, after all, quite small. They can even be negative, that is, they may have positive impacts: if the modeling is correct, the "cap-650" policy is *not costly* but *beneficial* to the world as a whole. Then, why is it so hard for the world to agree on such a policy? A major obstacle lies in the fact that the respective levels of direct costs and of avoided damage costs differ widely among countries. Indeed, a global policy, which is good for all when considered as an aggregate, may not be good for everyone, considered individually. We illustrate that with numbers provided by the CWS model for the "cap-650" policy. Fig. 5 shows avoided damage costs and direct costs geographically broken down as they occur in the 18 regions distinguished in the CWS model. Direct costs are displayed on the vertical axis, avoided damage costs on the horizontal one. Both are expressed as previously in percent of regional cumulated GDP until 2100.

< Please insert Fig. 5 around here >

< Please insert Table 1 not too far from Fig. 5 >

With this diagram the acceptability of a policy by each country can be characterized in three ways.

First, in terms of the respective importance of the domestic avoided damage costs and the direct costs each country incurs under the policy: if a country is located above the 45° line it experiences avoided damage costs larger than direct costs, which shows the policy to be domestically profitable. The country is likely to support that policy. By contrast, for a country located below the 45° line the policy is not domestically profitable, which makes the country likely to be against it. In either case, the larger the distance to the 45° line, the stronger the incentive to support or to reject the policy. The diagram thus shows distinct winners and losers.

Second, while a policy entailing avoided damage costs equal to direct costs for all countries would put them all on the 45° line, a globally beneficial policy with avoided damage costs larger than direct costs for all countries would put them all *above* the 45° line. By the same token, for any globally beneficial policy but not so for all of them, the points in the diagram would be scattered in such a way that the set of countries lying above the line enjoy profitability for a total amount larger than the total amount of losses incurred by those lying below.

Third, the radial distance of any point to the origin can be seen as an overall measure of how much is at stake macroeconomically for a country adopting the climate policy under consideration. Indeed, that distance expresses, in percentage points of the country's gross domestic product, the two cost components that we deal with in this paper, namely the direct cost on the abscissa and the avoided damage cost on the ordinate. For countries whose point is located close to the origin, both avoided damage costs and direct costs are only a minor proportion of their GDP, so that not much is at stake with the policy under consideration and the risk of wasting resources by erroneously supporting it is therefore not high. Things are different for countries located far from the origin: direct costs and/or avoided damage costs in that case are a large proportion of their GDP, and the consequences of making mistakes in the estimation of the policy's components, or in its implementation, constitute a much larger risk.

In view of the important uncertainties attached to the empirical assessments of the direct costs and avoided damage costs of climate change, be they large or small, one may invoke risk aversion to explain that the more a country is located away from the origin on this chart, the more likely it is to be reluctant to adopt the policy.

Finally, Fig. 5 suggests a classification of countries in three clusters:

- Cluster 1, composed of developed countries (e.g. USA, EU, JPN, CAN, OEU...): with moderate avoided damage costs as well as moderate *direct* costs, they have positive but weak incentives to support the "cap-650" policy, or weak opposition;
- Cluster 2, composed of less-developed countries (AFR, Mediterraneans, RAS...): they bear high direct abatement costs but also high avoided damage costs: so they *should* have strong positive incentives for supporting the "cap-650" policy;
- Cluster 3, composed of intermediate emerging countries (CHN, Middle East Asia, IND): they face high *direct* abatement costs but limited avoided damage costs, so they are likely to be strongly against (for CHN and MEA) or indifferent (IND) towards the "cap-650" policy; these three countries are also those for whom the "cap 650" policy entails the highest macroeconomic challenge (as measured in the Figure by their large radial distance away from the origin).

Fig. 5 shows that the "cap 650" policy would make some countries better off and some others worse off *w.r.t.* business-as-usual. Under such circumstances, can it at all be implemented, knowing that it requires a fully cooperative collective abatement effort among the countries? Answering this question raises two issues: (*i*) what is the burden sharing scheme implicit in the policy?, (*ii*) how are the net benefits shared in that policy?

As to burden sharing, the total abatement cost implied by the policy is supposed to be shared across countries in such a way that it be minimized, a feature of the model which simply applies the condition of equalization of the countries' marginal abatement costs. Thus, cost effectiveness at the world level is ensured.

As to the sharing of the net benefits, however, cost effectiveness does not ensure political acceptability, i.e. the fact that every country be willing to support the policy. Indeed, it is revealed by the Figure that for many countries/regions, the benefit they derive from it is lower than the cost they have to bear: on that basis, they would simply not support it. This is particularly true for China and Middle East Asia.

But the overall situation depicted by the Figure also suggests that they might nevertheless be *induced* to support such a policy if transfers of some kind (financial or economic resources) were envisaged from the winners to the losers, so as to bring the latter on, or above the 45° line. On Fig. 5, a transfer is visualized by a horizontal shift of the point that represents the country: to the left if the country receives the transfer, and to the right if the country contributes to the transfer.[8] Clearly, an acceptability condition of the transfer scheme is that it keeps the winners above the line too. This is in fact possible, but only if the policy under consideration generates a positive global amount of net benefits, i.e. a *negative global genuine cost*.

We reported above that with higher parameter values in the damage functions (2.7 instead of 2.0), the CWS model shows that the "cap 650" policy does generate such a positive global surplus (see Fig. 3). In this case, though, redrawing Fig. 5 shows that two countries would still not support the policy (namely, China and India). But since the global benefit of the policy is positive, the benefits of the countries located above the 45° line are sufficient to compensate these two countries for their losses, and bring them on the 45° line. This would make the "cap 650" policy compatible with *individual rationality*, to be understood here as the property that every country has an interest in the global policy and no one wishes to turn back to business-as-usual. This shows how national interests and the global policy are interlinked.

[8] Because the *x*-axis represents relative regional GDP losses or gains, the Euclidean distance does not display the absolute amount of transfers. So, the distances cannot be compared among countries.

In a recently developed literature on so-called "climate coalitions" this discussion of the individual incentives for countries to participate in international agreements with transfers is currently generalized to groupings of countries. Cost and benefits criteria as well as inter-country transfers are called upon, like here, to address the following more general question: can a coalition of countries, through an agreement among its members, be stable and effective when each country takes into account only its own costs and benefits? The present paper is a natural introduction to that literature.[9]

5. Summary and conclusion

The message of this paper is a simple one. That preventive actions against the effects of climate change are costly is widely argued; that the thereby avoided damage costs are even more considerable is less advertised. Yet, these are two equally inescapable components of the problem. While the huge complexity of both the physical and the economic aspects of the problem justifies the recourse to highly sophisticated modeling techniques, benefit-cost analysis is also necessary to provide justification of action, because it is a simple and basic tool of economic reasoning, as well as a powerful instrument to convince the public at large.

In this paper, we propose to evaluate climate policies by combining the two approaches of modeling and benefit-cost analysis. That combination is possible if the economic modeling is complete, that is, if it covers what we have called the genuine cost of policies and not only their direct costs. We conclude in terms that are precise enough for decision taking, excluding some policies (e.g. the one aiming at the concentration objective of 550 ppm), and supporting other ones (e.g. 650 ppm). For sure, the model we use is a stylized one and its parameter values are quite uncertain. Yet the gist of our conclusion is less in the absolute numbers themselves than in the virtues of the two-fold methodology that allowed to formulate them.

In that spirit we have replicated with our own model the previous and path breaking approach of Stern (2007). Contrary to what some might call a repetition, such replication is an essential component of modeling methodology, as is well known in physical sciences. Given the utmost economic importance of the policy decisions to be made, it would be foolish to satisfy ourselves with just one estimate. Only repeated studies, if reasonably converging in their conclusions, can provide a credible basis for action on climate change.

By breaking it down in its multi-country or regional dimensions, our benefit-cost analysis further points out, by means of a simple diagram, what is probably the hardest obstacle to international cooperation in climate affairs, namely the economic fact that avoided damage costs and direct costs differ

[9] See Bréchet et al. (2011) for an expository presentation of the stability and effectiveness concepts, with numerical illustrations, and an extended list of relevant references.

widely across countries, and across policies. For some countries, avoided damage costs do not reach the level of the direct costs they will endure even under an optimal policy: hence they resist joining international agreements that would require them to curb their emissions. In other countries, the avoided damage costs do outweigh the direct costs of mitigation. Thus, there is room for the latter to compensate the former in some way. But payment of such compensations also triggers resistance. While an economic analysis like the one above does show that such a scheme is feasible, its implementation requires in addition considerable diplomatic skills to overcome the said resistances, as experienced by the long and patient negotiation process of the UNFCCC.

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Table 1. Countries/regions in the CWS model

AFR	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Congo Dem. Republic, Ivory Coast, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambian Zimbabwe
AUZ	Australia, New Zealand
CAN	Canada
CEA	Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia,
CHN	China, Hong-Kong
EAS	Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam
EU	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom
FSU	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
IND	India
JPN	Japan, Korea (South)
LAM	Argentina, Brazil, Chile, Mexico, Paraguay, Peru, Venezuela
LAO	Bahamas, Belize, Bolivia, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Suriname, Trinidad & Tobago
MEA	Bahrain, Iran, Jordan, Kuwait, Oman, Saudi Arabia, United Arab Emirates, Yemen
MED	Algeria, Egypt, Israel, Lebanon, Morocco, Syria, Tunisia, Turkey
OEU	Iceland, Norway, Switzerland
RAS	Bangladesh, Cambodia, Laos, Mongolia, Nepal, Pakistan, Papua New Guinea, Sri Lanka
ROW	Albania, Barbados, Bhutan Brunei, Croatia, Fiji, Korea (North), Macedonia (FYR), Maldives, Myanmar, Saint Lucia, Saint Vincent & Grenadines, Samoa, Sao Tome & Principe, Serbia & Montenegro, Solomon Islands, Tonga, Vanuatu
USA	United States of America

Figure 1. World GHG emissions in the two policies and two scenarios

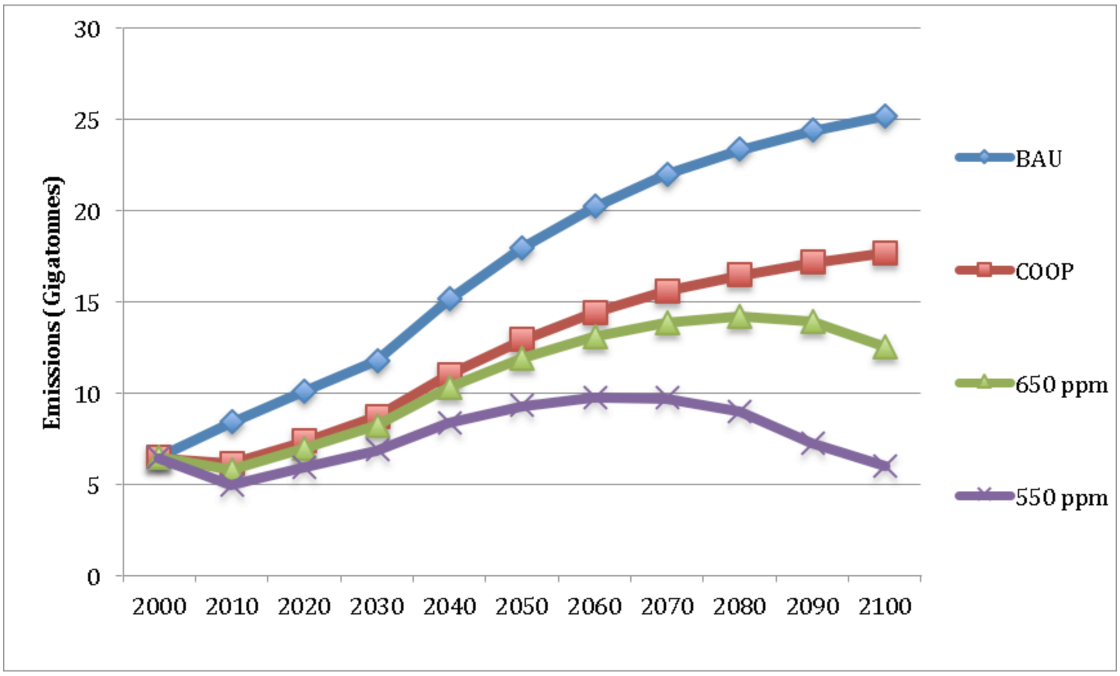

Figure 2. Direct costs, damage costs avoided, and genuine costs of the "cap-550", "cap-650" policies and of the "COOP" scenario. Measured in % of world GDP, cumulated over the period 2000-2100, by means of the CWS model

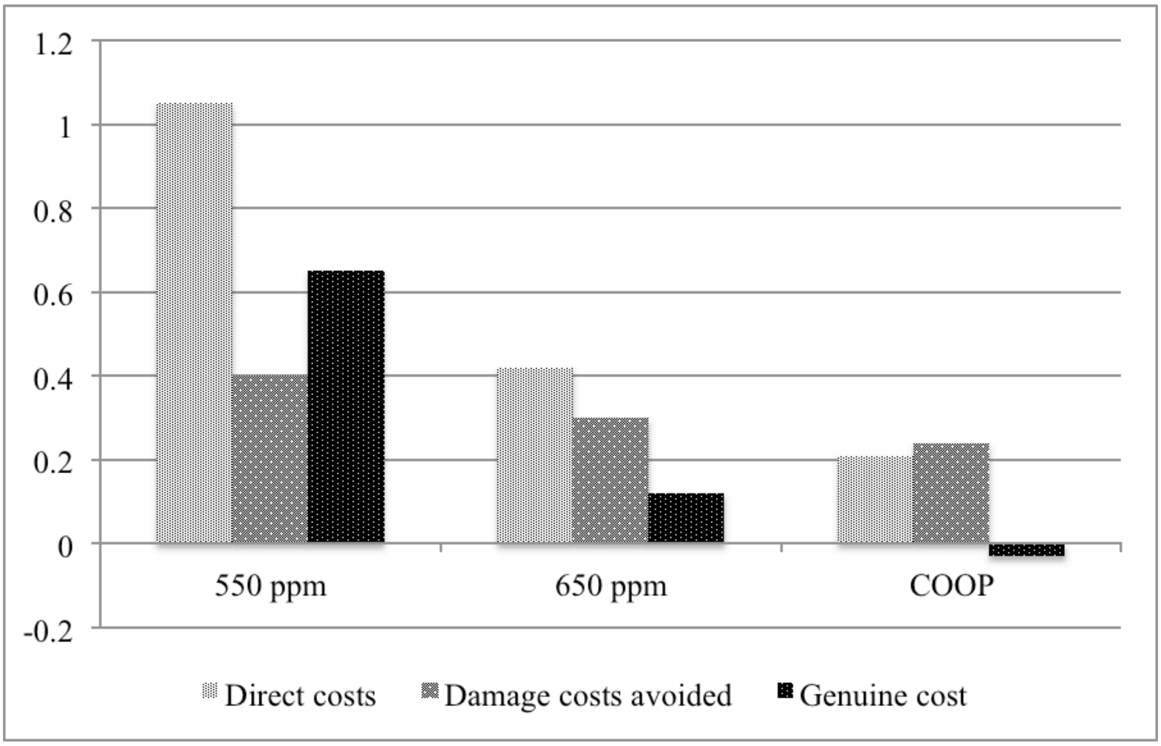

Figure 3. World GHGs emissions with steeper damage functions in the two policies and two scenarios (remarkable: the optimal 650 ppm trajectory and COOP almost coincide in this case)

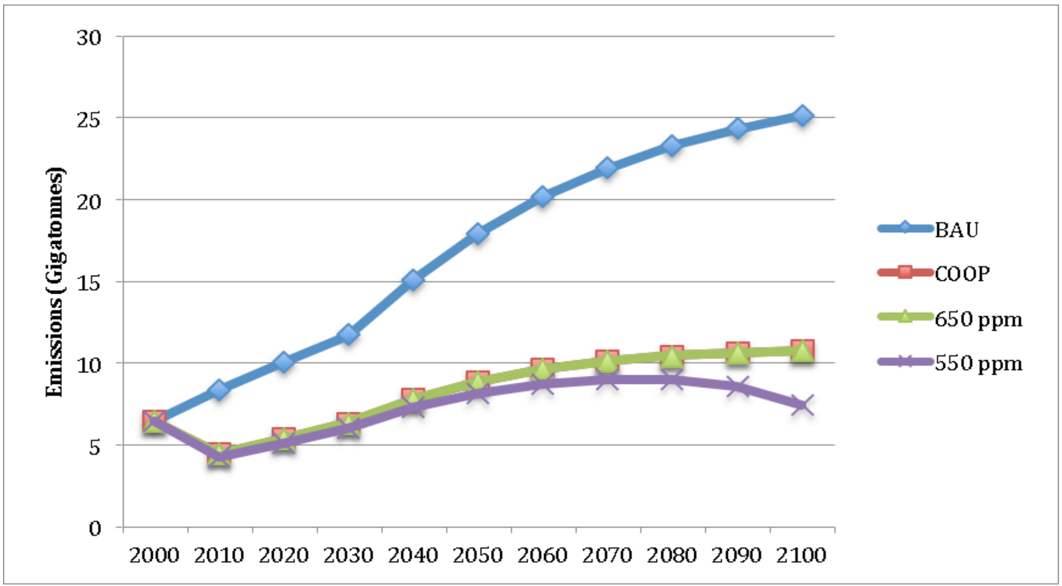

Figure 4. Sensitivity analysis for direct costs, avoided damage costs and genuine costs
for "cap-550", "cap-650" policies and "COOP" scenario,
with steeper damages functions

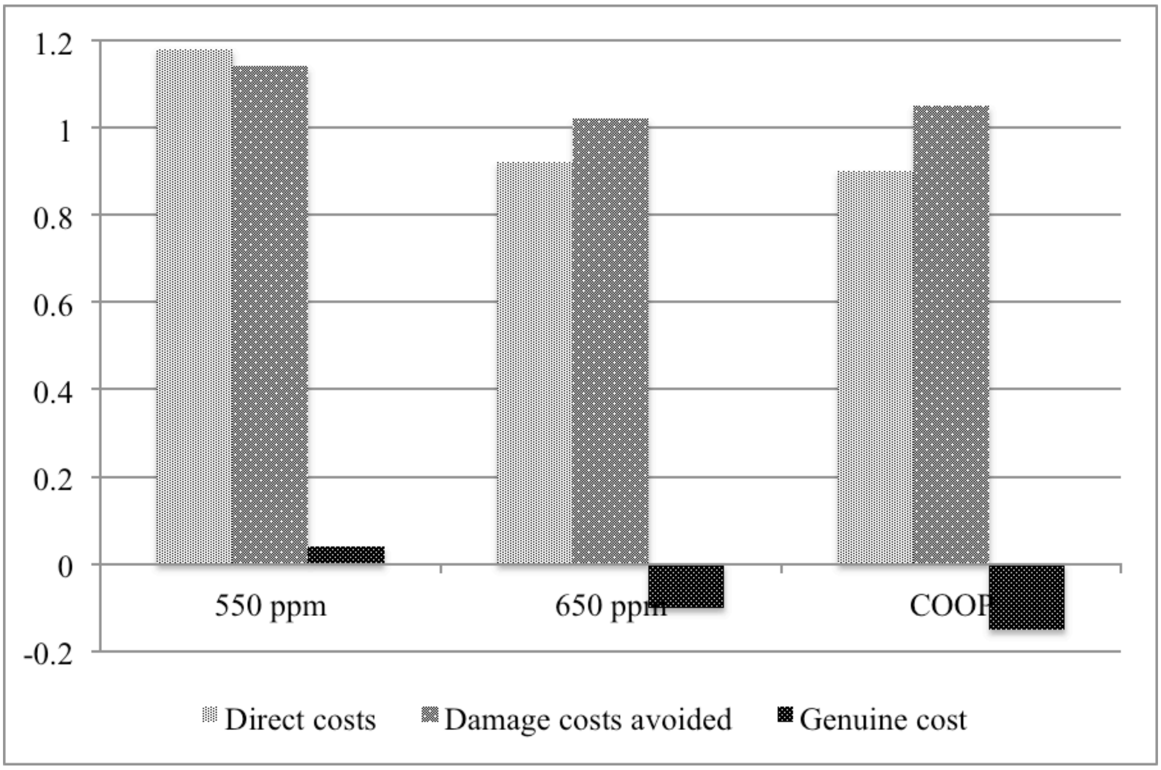

Figure 5. Costs (i.e. direct costs) *versus* benefits (i.e. avoided damages) at the regional level for the "cap-650" policy *(for country codes, please refer to Table 1)*